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Sensing Room Environment: Distributed Sensor Space for Measurement of Human Daily Behavior†

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This paper describes construction of "Sensing Room", which is a behavior measurement space equipped with distributed sensors. In the room, there are a floor, a table and chairs embedding pressure sensors, electric appliances and furniture with switch sensors, and a lot of objects attached with id tags that can be identified by object tag sensors in the room and many others. By utilizing the embedded multiple sensors, the room can measure natural daily behaviors without constraint or restriction. The sensors are all arranged as module structure. The modules are connected each other in network. Layer structure model realizes long-term accumulation and reliable measurement of sensor data. Since users can collect sensor data on-line, they are able to create on-line applications flexibly.

Key Words: Distributed Sensing System, Sensing Environment, Measurement of Daily Behavior

1. Introduction

On a background of small, power-saving and cheap sensors, recently devices become to have more advanced functions by embedding the sensors. And by the network growth, not using a single device but combining multiple devices through the network leads to new applications. Especially, home environments may be sensorized remarkably. That is because it is easier to equip the sensors and to introduce sensorized devices (ex. home information appliances) into the home than outdoors. Existing home applications are likely to focus on automation of simple operations. For the future, it is necessary to support the habitants fitting to their individual characteristics by utilizing a large number of distributed sensors in the home. In respect of human interface, it is more suitable for applications to support the habitants initiatively than for the humans to command the applications purposely. In order to realize such initiative support, home environment that can always monitor the occupants and recognize natural daily behaviors is needed.

House_n Project [1] tries to measure and recognize human behaviors by not only attaching the on/off sensor called "Tape-on" and vision sensor but also interviewing the occupants via PDA carried with them. The main purpose of the project is off-line analysis of sensor data. Also, AIST Sensorized Environment [2] observes and tries to recognize human actions in sensorized room-type environment. Our research can realize on-line applications as well as measurement and recording of human behaviors. Aware Home [3] is a home equipped with many cameras, microphones, RFID tag sensors and finger print verifiers. The home can measure only position of persons in the home. It cannot measure or recognize human behaviors in detail. Easy Living [4] aims to create applications fitting habitant behaviors by means of cameras, RF position sensor, and finger print verifiers. The project mainly measures the occupants' positions in the room and how they use the computers. Ogawa, Virone and Barger have been trying to analyze human's health status by measuring daily behaviors using sensors [5)~7)]. MavHome [8] and Vivid Room [9] realize recognition of human behaviors and simple support applications by equipping on/off sensors with the rooms. Since the sensors are simple, the behaviors that are able to be measured are limited (ex. reading or working). In our research, positions of objects are achieved and many kinds of behaviors including ambiguous behaviors can be measured.

Our laboratory has been developing Robotic Room 1 [10] and Robotic Room 2 [11),12)] for measurement of human behaviors. However, the room is inefficient for recognition of objects in the room. By expanding Robotic Room 2, distributed sensing environment "Sensing Room Environ-

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ment" is constructed. The room can measure detail of human daily behaviors in a long term without restriction both off-line and on-line.

2. Distributed Sensor Management

In this research, target behaviors are not only simple behaviors that can be named easily (ex. sleeping and eating), but also ambiguous behaviors that is difficult to be called (ex. walking around). In order to measure such human behaviors from embedded sensors in a room, it is important to attach multiple sensors all over the room. By using the sensors in the room, all motion when the habitants contact with the environment should be measured. The motions are touching objects in the room, operation of the devices, and moving and changing of the objects in the room.

In case of a few sensors, it is easy and reliable that the sensors are connected in a hard-wired way and sensor signals are collected together. As the number of the sensors get large, it is difficult to presume static configuration of the sensors and to manage the sensors. In this research, mechanisms for uniform handling of the multiple sensors are introduced. They are module and layer structure. In another respect, the mechanisms are abstraction of properties and functions of the sensors, and unification of sensor data processing.

2.1 Sensor Module Structure

Generally speaking, there are two ways how the sensors are introduced into the room. For one way, when new appliances come into the home or when old ones are replaced with new ones, the sensors are brought together with the appliances. The examples are electric appliance that can record history of operations and a bed with sensors that is able to measure vital data during sleeping. For another way, the sensors are embedded in a functional unit when building the house. For example of the case, a lot of the temperature sensors are embedded for precise automation of air conditioning. Cameras may be equipped all over the room, for tracking the persons in a room. In this research, each of these sensor unit is called "sensor module". The sensors are treated in module unit. The module structure are helpful for management of a lot of multiple sensors.

2.2 Layer Structure for Sensor Data Processing

If sensor data are only utilized off-line, only the module structure is sufficient for managing sensors. For utilizing the sensor data on-line, unification of sensor hardware and sensor data processing is desirable. In Sensing Room Environment, layer structure is adopted in order to abstract

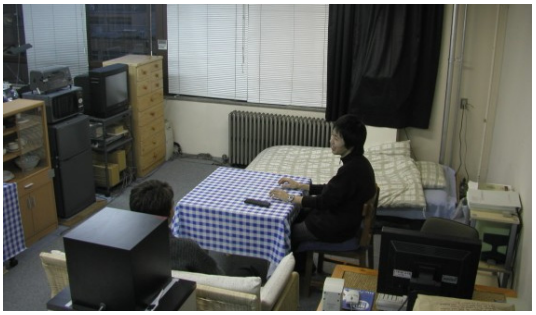


Fig. 1 Outlook of Sensing Room Environment

communication of sensor data in software and hardware. The structure has the following merits. 1) In the lower layers, differences of the sensors are absorbed. Adaptation to multiple sensors is realized. 2) The different modules can share the same function. When new sensors are introduced and they are similar to the previous sensors, the previous hardware and software are reusable and trouble of introduction lessens. 3) Even though program or hardware change in a layer, the change does not influence the programs and hardwares in the other layers. The replacement and addition of sensors are conducted flexibly and easily.

3. Implementation of Sensing Room Environment

Considering above distributed sensor management, Sensing Room Environment is constructed. Outlook of Sensing Room Environment is shown in **Fig. 1**.

3.1 Implementation of Sensor Modules

Sensor modules in Sensing Room Environment is illustrated in **Fig. 2**.

Sensor modules are mainly divided into three types: 1) Touch detection type: the modules in the type measure that persons contact the room environment from pressure sensors. The modules of this type are a floor module, a table module, a bed module, chair modules, and a sofa module. 2) Operation detection type: the modules in the type detect operation of the occupants from switch sensors. The modules in this type are a electric appliances and furniture switch module and kitchen cabinet module. 3) Object identification type: the modules in the type identify objects in the room and measure positions of the objects. The modules help to assume that the persons handling the objects. The module in Sensing Room Environment are object id modules such as RFID tag sensors.

3.2 Implementation of Layers

Layer structure in Sensing Room Environment is four-layer structure like **Fig. 3**. Function of each layer is de-

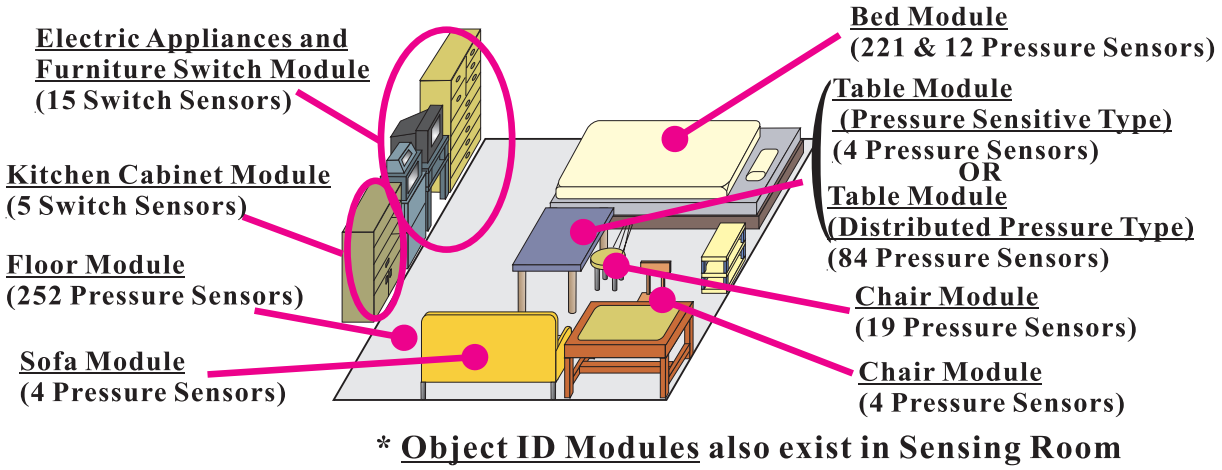


Fig. 2 Sensor Modules in Sensing Room Environment

scribed in the following.

3.2.1 Sensor Layer

In this layer, sensing about human behaviors is performed. There are sensor elements and electric circuits for the sensors in the layer [13]. The layer absorbs the difference among the sensors.

3.2.2 Sensor Output Linkup Layer

In the layer, the devices collect sensor outputs in a module and deliver outputs to other devices. Hardware in the layer is microprocessor board with OS or compact PC. Software is a simple program for data transfer via TCP/IP socket. The program sends sensor outputs in response to calling from other network programs. The layer enables to share the sensor outputs in the same hardware.

3.2.3 Sensor Data Processing Layer

In the layer, sensor data is converted into other sensor data, because some sensor data cannot be utilized directly. The examples are sound signals and sensor outputs from pressure sensors in grid. The preprocessing for the sensors is conducted in the layer, i.e., some meaningful information is extracted from sensor data. Hardware is high-performance PC. Software is a program based on distributed object technology [14]. Applications can invoke the programs in network transparently.

3.2.4 Application Layer

In this layer, applications work. The programs integrate sensor data and support the occupants. Both on-line application and recording applications are running simultaneously [15]. While the users analyze sensor data about human behavior, they can create on-line application and try it.

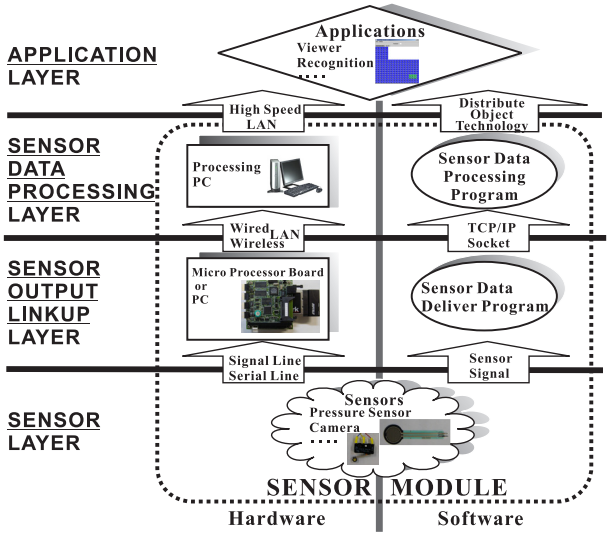


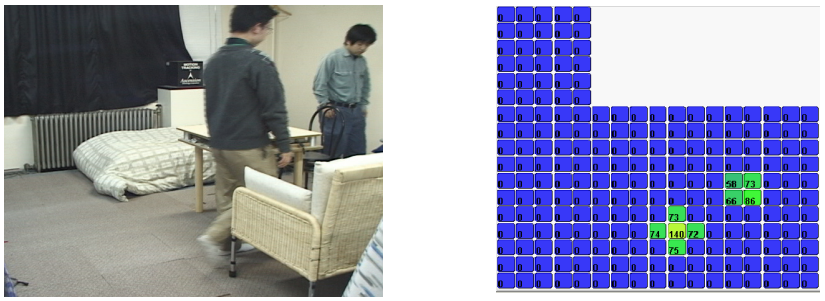
Fig. 3 Layer Structure for Sensor Data Processing in Sensing Room Environment

3.3 Typical Modules in Sensing Room Environment

3.3.1 Floor Module

One of the most important sensor modules in Sensing Room Environment is a floor module. The position where the occupant stands is important for recognition of human behaviors. For example, walking in front of a kitchen and in front of a book shelf are different behaviors, even if the human is walking around by the same way. In the home, except sitting on a chair or lying on a bed, the human always contacts with the floor surface. The floor module can measure the habitants' whereabouts robustly.

Configuration of sensors in the floor module is shown in **Fig. 4**. In the module, pressure sensors called FSR (Force Sensing Register) are utilized. The sensor has problems about hysteresis and drift. However, since its shape is a



A) Example Scene: Two Persons are Standing B) Output Display of Floor Module

Fig. 5 Output Example of Floor Module

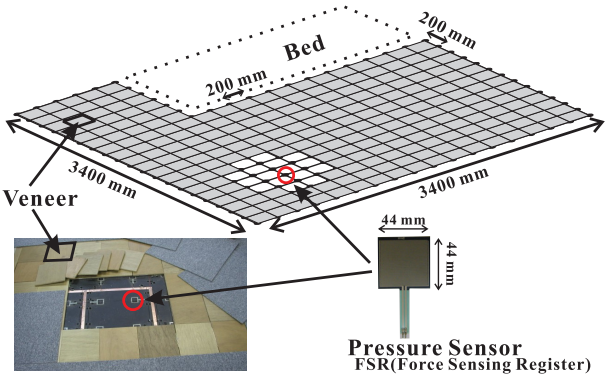


Fig. 4 Layout of Sensors in Floor Module

A)Chair Sensors Photo and Layout B)Output Example of Chair

Fig. 6 Layout of Sensors in Chair Module

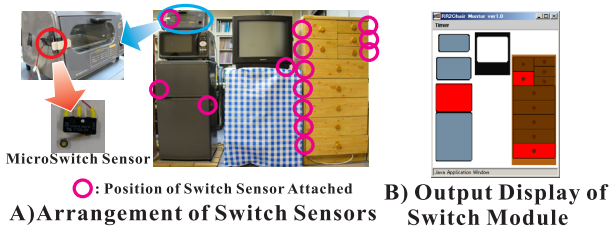


Fig. 7 Configuration and Output Example of Switch Module

sheet and it is crashworthy, the sensors are mounted with a room and maintained easily. The sensors are embedded in 20 cm intervals. There are veneer tiles on every 4 pressure sensors.

A scene and the program snapshot of the floor module are shown in **Fig. 5**. The floor pressure data is regarded as a grayscale image by averaging the pressure sensor outputs in each veneer tile. The positions of the persons are calculated by taking from background difference, eliminating noise data by threshold, labeling tile data and calculating centers of the labels. The module can calculate human standing positions from all pressure sensors in 10Hz.

3.3.2 Chair Modules

All of the chairs in Sensing Room Environment is equipped with sensors. Most of these chair sensor modules have FSR pressure sensors that are the same as floor module's. The FSR sensors are attached under the chairs' legs(**Fig. 6**). The chair module can measure the habitants' sitting status and direction robustly.

3.3.3 Electric Appliances and Furniture Switch Module

Conditions of electric appliances and furniture are important for recognition of human behavior. For instance, a power status of a television is a key for decision whether a person is watching the television. Doors and power switches of all electric appliances and furniture in Sensing Room Environment is attached with microswitch sensors. Configuration and program snapshot of the module are illustrated in **Fig. 7**. There are 15 switch sensors in the room. They are measured by10 Hz.

3.3.4 Object ID Modules

Operation for objects in room is significant for recognition of human behaviors. For example, in case of working on a desk, treating with a book on a desk is different from that with a cup. The object id sensors can measure the difference. In this research, RFID(Radio Frequency IDentification) tag sensors are adopted. The RFID tag sensor consists of object id tags and tag readers that can read data of the tags. When a tag enters the area where a reader can communicate, the reader supplies electric power to the tag by RF, obtains the tag information and identifies the tag. Since the communication area of the

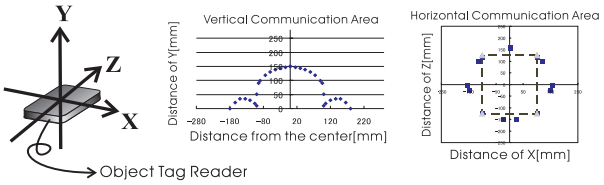


Fig. 8 Communication Area of Object Tag Reader

reader is limited, rough position of the object can be assumed. Since the id tag is very small and RF is transparent for the objects except metals and water, most of all objects in the room can be attached with the tag.

The RFID tag sensor in Sensing Room Environment has 125 KHz frequency band. The tag reader can communicate with the tags in 15cm distance from the top of the reader. The tag size is 2cm diameter. The sampling of the module is about 5Hz. The communication range of the object tag reader is show in **Fig. 8**.

Since there are some electric wave interference between tag readers, it is difficult to embed a lot of tag readers in one room. Based on several interference experiment and the room layout, we decided the arrangement of the object tag reader module as shown in **Fig. 9**.

4. Sample Application

Here we show a preliminary trial of human behavior recognition using Sensing Room Environment. The prototype system recognizes human behaviors based on simple rule descriptions. Relation between a start and end point of human behaviors and series of sensor outputs is described by the rules. The system decides behaviors based on whether the rule matches the sensor output in order of time. **Fig. 10** shows a snapshot of the recognition program. Based on the recognition, the such information supports as behavior search and life-style review will be realized. This application is based on many very simple behavior recognition rules. Since the distributed sensors are closely related to human's behaviors, the recognition rules become simple.

A monitoring application is also created. The application assumes the state of a habitant and displays as a 3D image on-line(**Fig. 11**). The information of the occupant can be also monitored by a mobile phone application(**Fig. 12**). The application will be helpful for monitoring remote elderly people.

5. Conclusion

Distributed sensing space "Sensing Room Environment" is constructed. Sensing Room can measure and

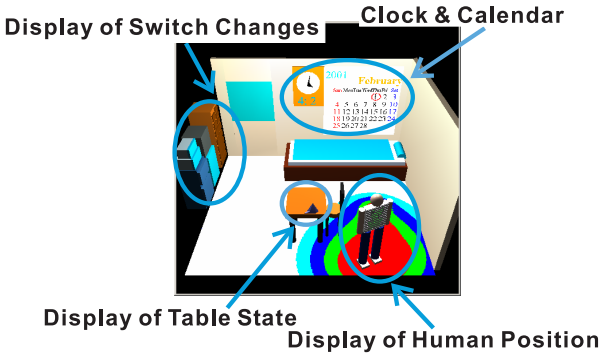


Fig. 11 A Snapshot of Occupant Display Program

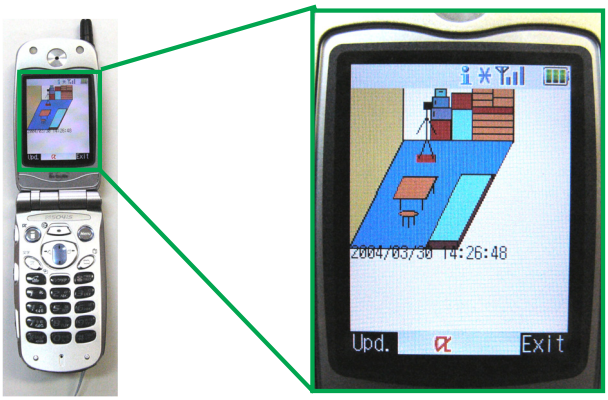


Fig. 12 A Snapshot of Mobile Phone Application

record daily human behaviors with a large number of sensors in the room. Module structure and layer structure resolve the problem how to manage multiple sensors and programs. We are working on several applications for supporting daily behavior and analyzing patterns of human behaviors measured by the room.

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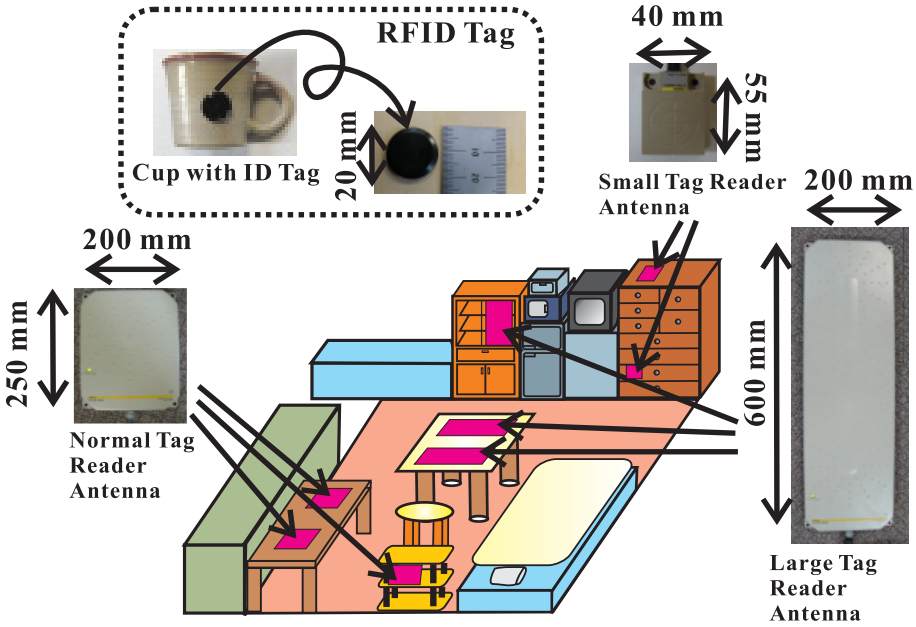

Fig. 9 Arrangement of Object ID Module

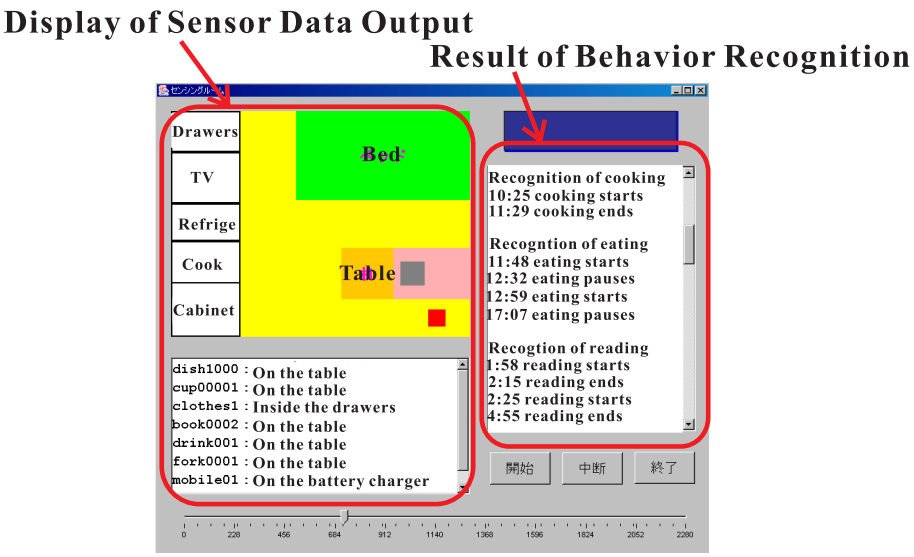

Fig. 10 A Snapshot of Human Behavior Recognition Program

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